US009230578B2

(12) **United States Patent**
Batra et al.

(10) **Patent No.: US 9,230,578 B2**
(45) **Date of Patent: Jan. 5, 2016**

(54) **MULTIPLE READERS FOR HIGH RESOLUTION AND SNR FOR HIGH AREAL DENSITY APPLICATION**

(71) Applicant: **HGST Netherlands B.V.**, Amsterdam (NL)

(72) Inventors: **Sharat Batra**, Plymouth, MN (US); **Jonathan D. Coker**, Rochester, MN (US); **Travis R. Oenning**, Rochester, MN (US)

(73) Assignee: **HGST Netherlands B.V.**, Amsterdam (NL)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/138,804**

(22) Filed: **Dec. 23, 2013**

(65) **Prior Publication Data**

US 2015/0179193 A1 Jun. 25, 2015

(51) **Int. Cl.**
G11B 5/39 (2006.01)

(52) **U.S. Cl.**
CPC ***G11B 5/3954*** (2013.01); ***G11B 5/3909*** (2013.01)

(58) **Field of Classification Search**
CPC G11B 2005/3996; G11B 5/3954; G11B 5/3932; G11B 5/3945; G11B 5/3948; G11B 5/3951; G11B 5/3909
USPC 360/314–316, 319, 324–342.2
See application file for complete search history.

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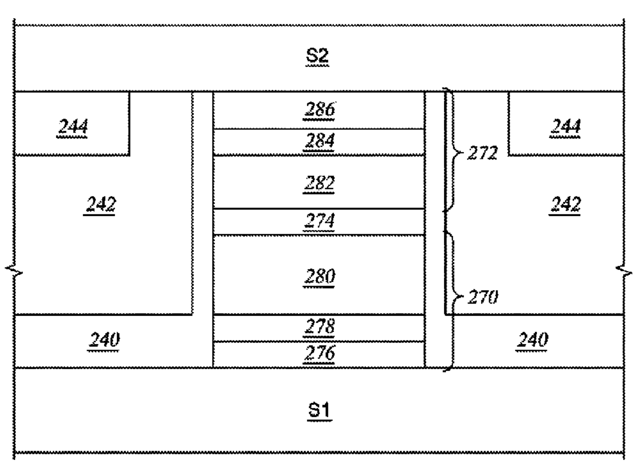
Primary Examiner — Will J Klimowicz
(74) *Attorney, Agent, or Firm* — Patterson & Sheridan, LLP

(57) **ABSTRACT**

The present invention generally relates to a read head in a magnetic recording head. The read head utilizes two reader elements that are stacked in the down track direction within the same read gap to improve resolution and SNR by combining the signals from the two reader elements. The output waveform from each read element is asymmetric in the down track direction; however, by use of equalizer settings and waveform combining the algorithm in signal processing, the combined waveform has a similar or better resolution and higher SNR compared to a single read element in a smaller read gap.

19 Claims, 8 Drawing Sheets



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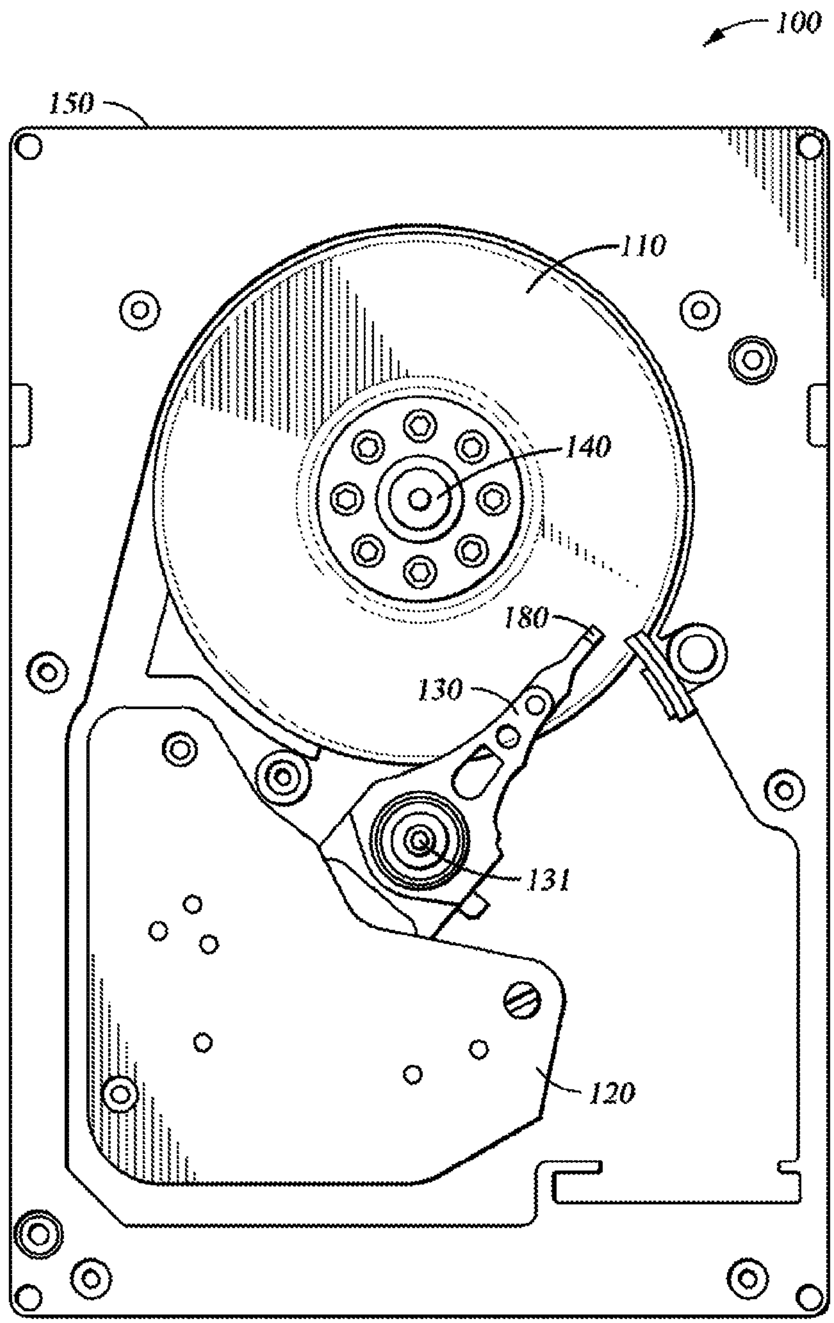


Fig. 1

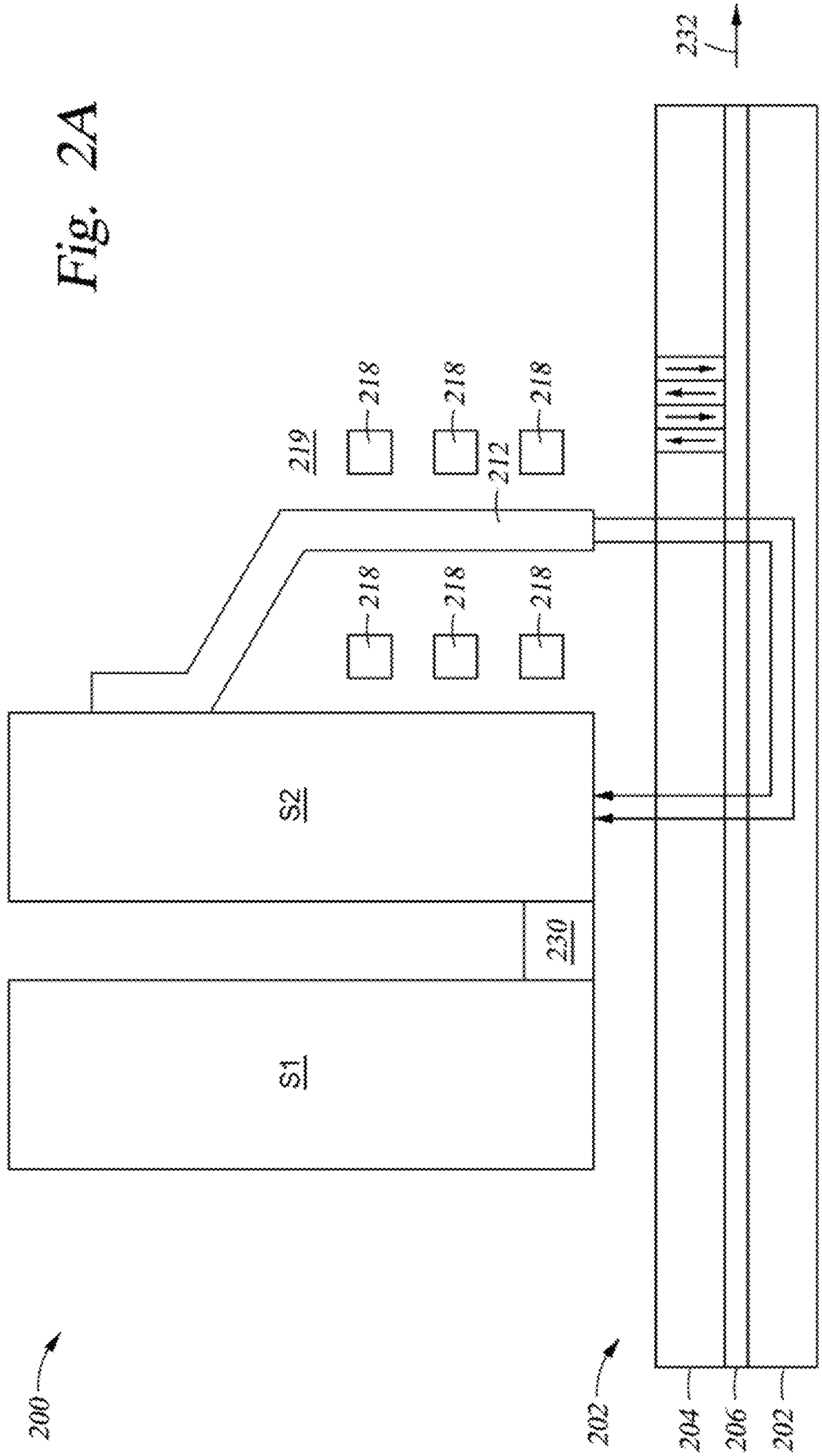


Fig. 2A

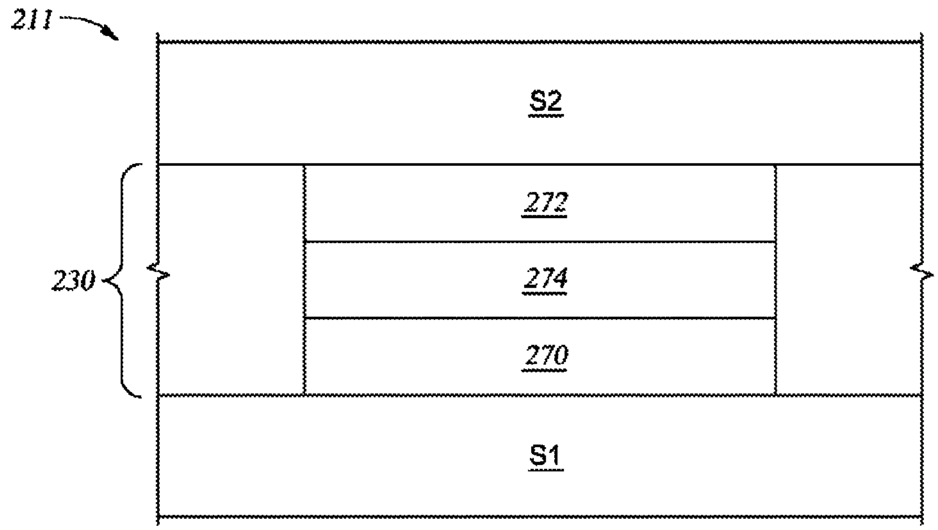
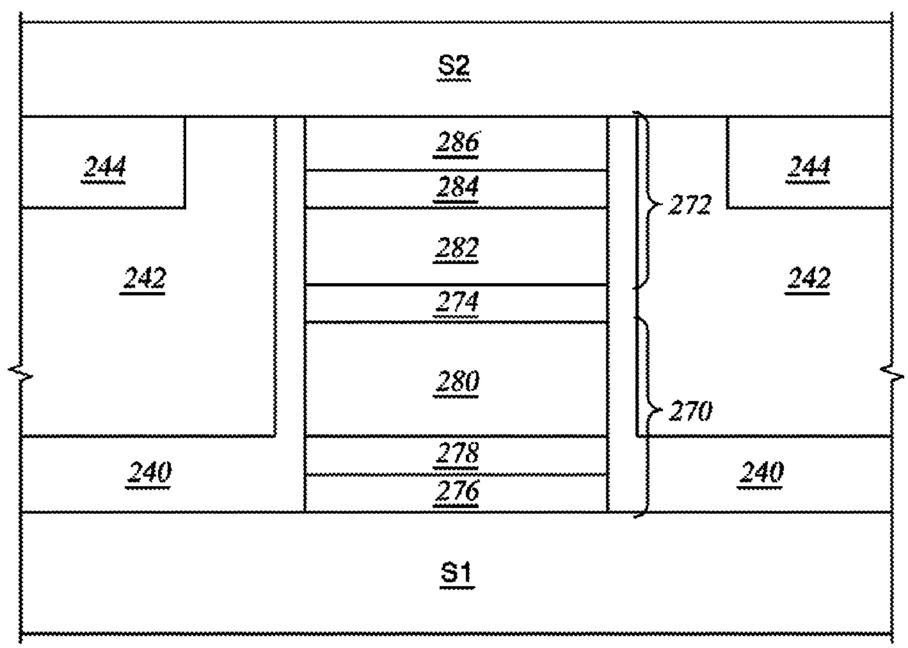

211
S2
272
274
270
230
S1

Fig. 2B


S2
244
286
284
282
274
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278
276
244
242
242
240
240
272
270
S1

Fig. 2C

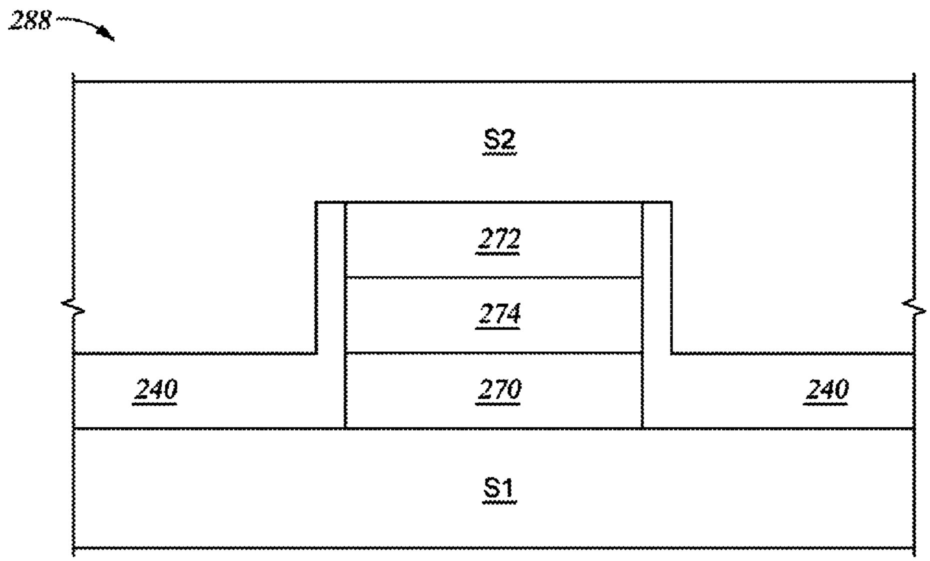
288
S2
272
274
240
270
240
S1

Fig. 2D

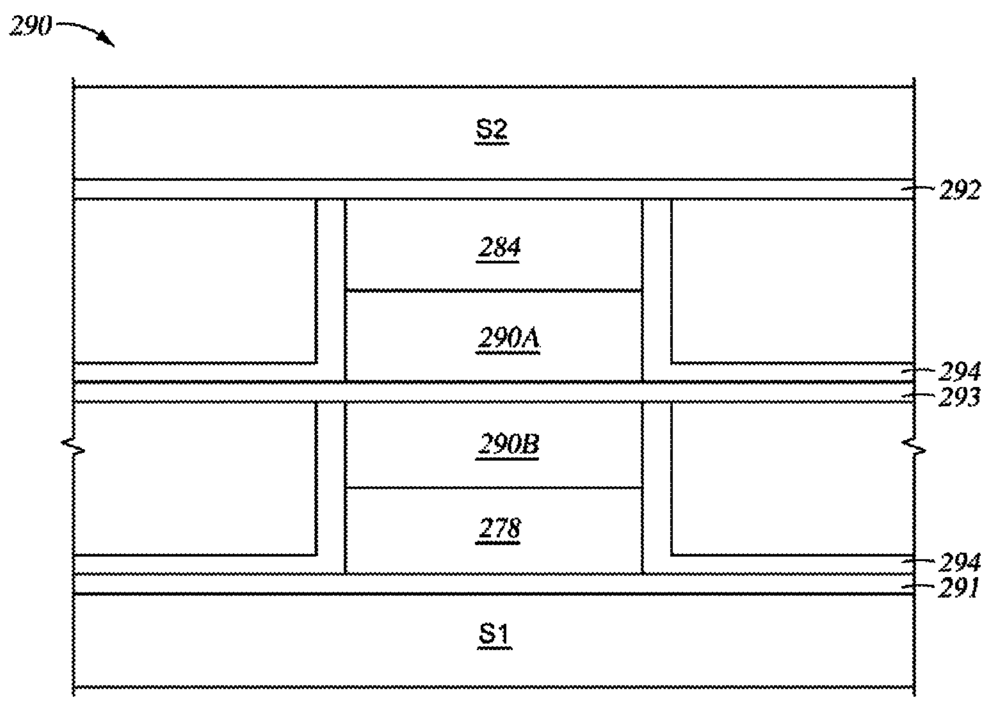
290
S2
292
284
290A
294
293
290B
278
294
291
S1

Fig. 2E

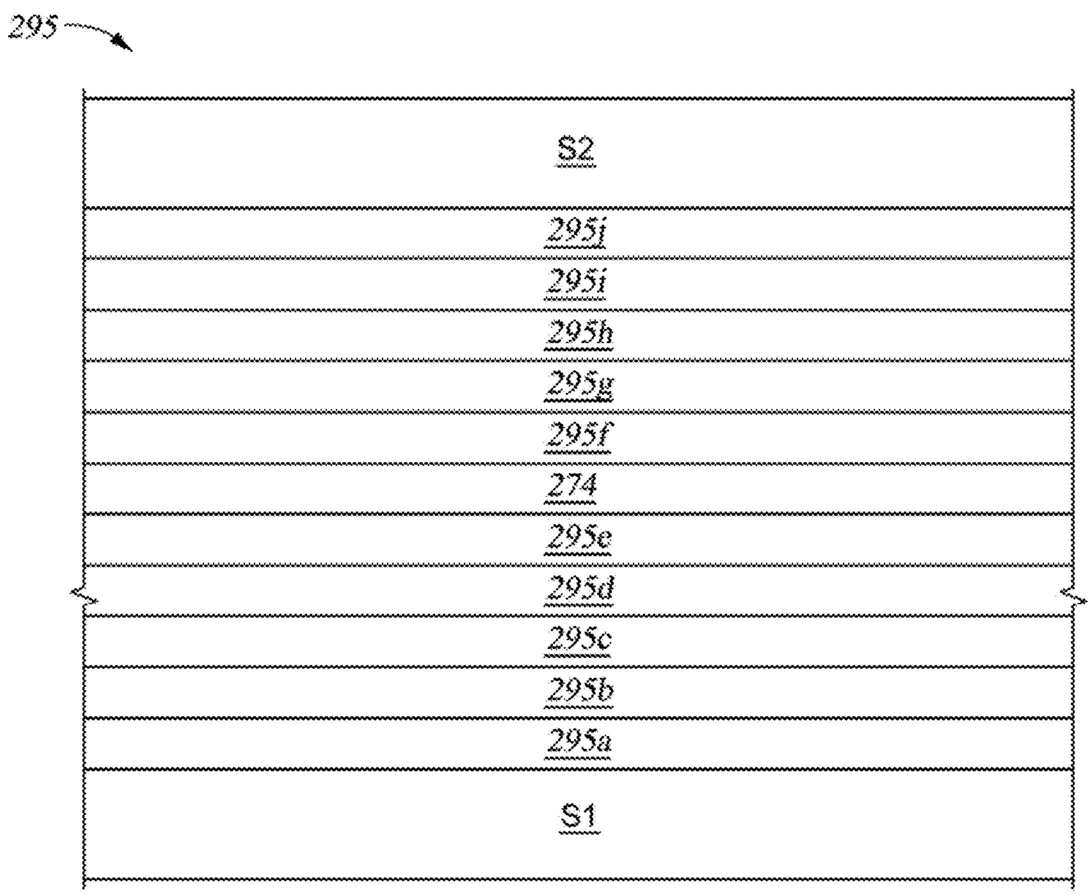
295
S2
295j
295i
295h
295g
295f
274
295e
295d
295c
295b
295a
S1

Fig. 2F

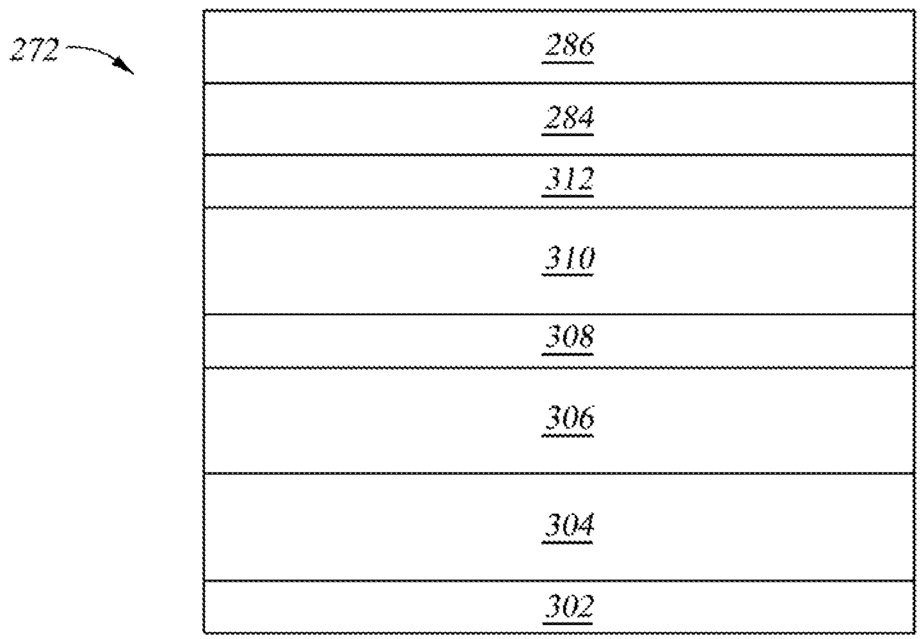
272
286
284
312
310
308
306
304
302

Fig. 3A

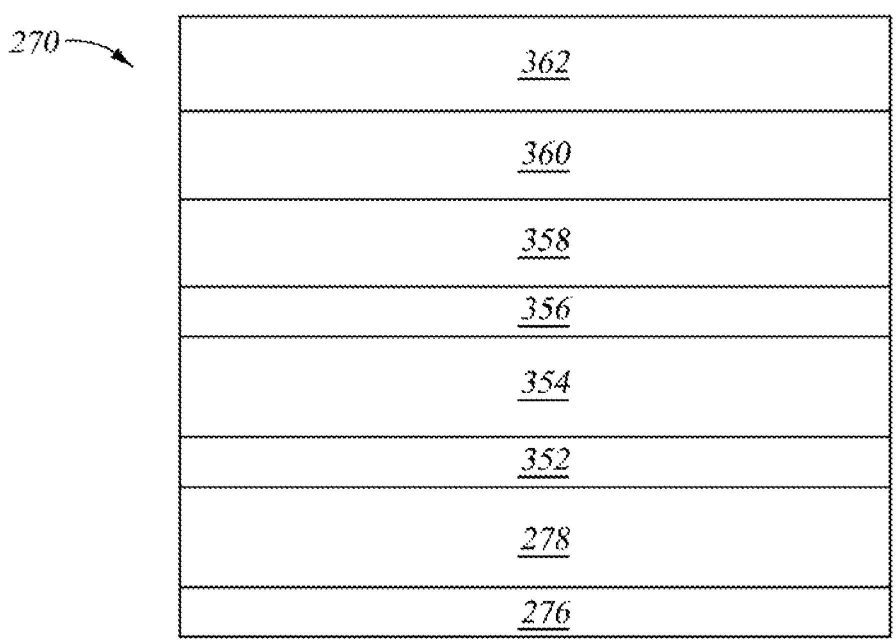
270
362
360
358
356
354
352
278
276

Fig. 3B

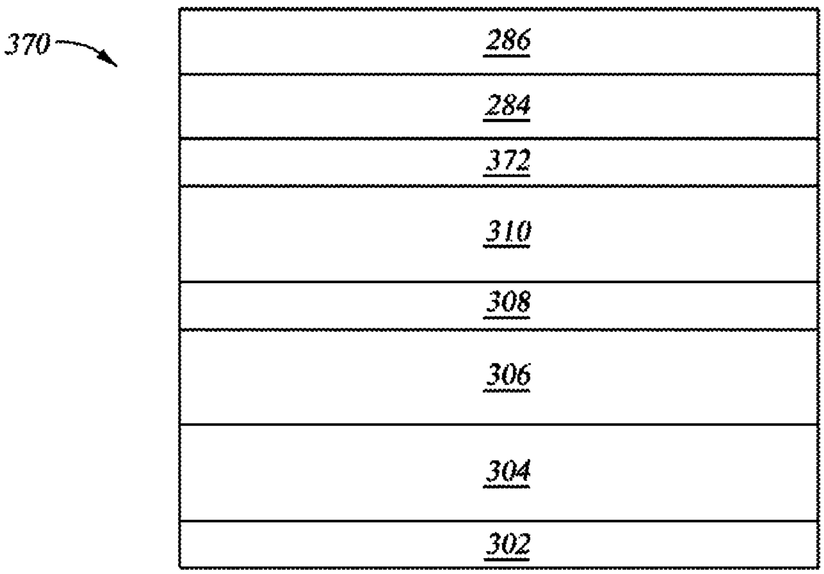
370
286
284
372
310
308
306
304
302

Fig. 3C

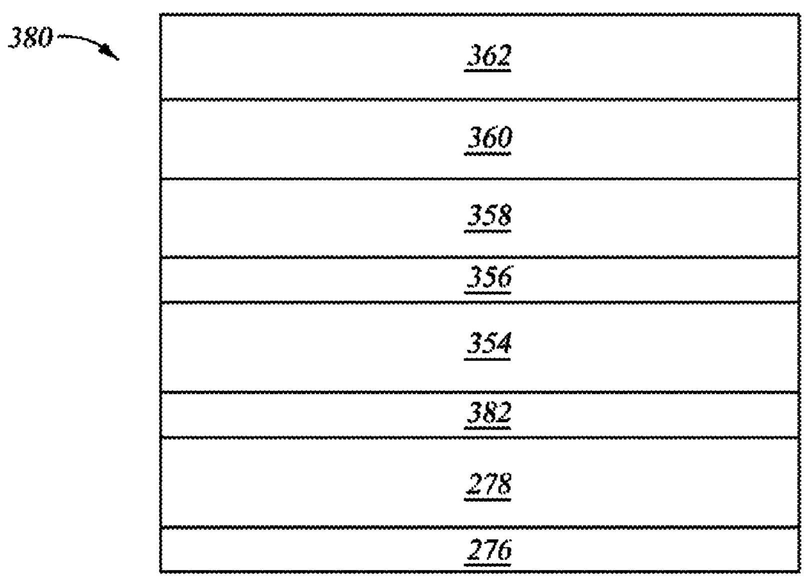
380
362
360
358
356
354
382
278
276

Fig. 3D

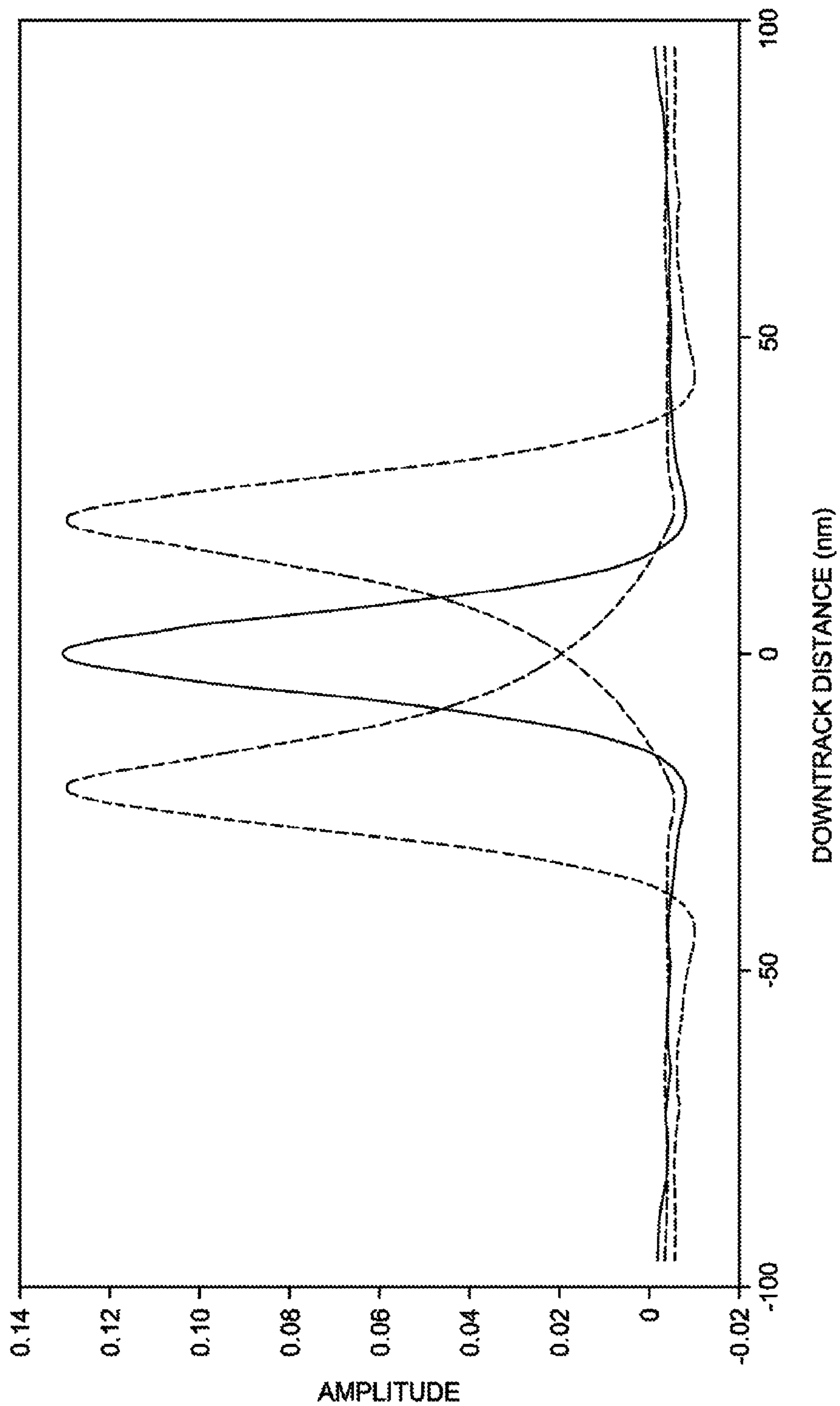
AMPLITUDE
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
-0.02
DOWNTRACK DISTANCE (nm)
-100
-50
0
50
100

Fig. 4

MULTIPLE READERS FOR HIGH RESOLUTION AND SNR FOR HIGH AREAL DENSITY APPLICATION

BACKGROUND OF THE INVENTION

1. Field of the Invention

Embodiments of the present invention generally relate to a magnetic read head for use in a hard disk drive.

2. Description of the Related Art

The heart of a computer is a magnetic disk drive which typically includes a rotating magnetic disk, a slider that has read and write heads, a suspension arm above the rotating disk and an actuator arm that swings the suspension arm to place the read and/or write heads over selected circular tracks on the rotating disk. The suspension arm biases the slider towards the surface of the disk when the disk is not rotating but, when the disk rotates, air is swirled by the rotating disk adjacent an air bearing surface (ABS) of the slider causing the slider to ride on an air bearing a slight distance from the surface of the rotating disk. When the slider rides on the air bearing, the write and read heads are employed for writing magnetic transitions corresponding to host data. The read and write heads are connected to a signal processing circuitry that operates according to a computer program to implement the writing and reading functions.

Improved signal to noise ratio (SNR) in magnetic recording involves improved reader resolution in the down-track and cross-track directions to enable reading the closely packed transitions on a narrow track. Reader resolution and SNR is mostly determined by the reader sensitivity (dR/R), RA product and shield to shield spacing. Most of the gains in readers have come from continuous improvement in the film stack and reduction in shield to shield spacing. The material limits are just about reached.

Therefore, there is a need in the art for an improved read head.

SUMMARY OF THE INVENTION

The present invention generally relates to a read head in a magnetic recording head. The read head utilizes two reader elements that are stacked in the down track direction within the same read gap to improve resolution and SNR by combining the signals from the two reader elements. The output waveform from each read element is asymmetric in the down track direction; however, by use of equalizer settings and waveform combining the algorithm in signal processing, the combined waveform has a similar or better resolution and higher SNR due to noise averaging compared to a single read element in a smaller read gap.

In one embodiment, a magnetic read head comprises: a first shield layer; a second shield layer; a first sensor element disposed between the first shield layer and the second shield layer; and a second sensor element, separate and distinct from the first sensor element, disposed between the first shield layer and the second shield layer. A magnetic or nonmagnetic conducting material may be used as a center lead that is coupled between the first and second sensor elements.

In another embodiment, a magnetic read head comprises: a first shield layer; a first sensor element disposed on the first shield layer; a center lead disposed on the first sensor element; a second sensor element disposed on the center lead; and a second shield layer disposed on the second sensor element.

In another embodiment, a magnetic read head comprises: a first shield layer; a first sensor element disposed on the first shield layer, the first sensor element comprising a first free

magnetic layer, wherein the first free magnetic layer is disposed a first distance from the first shield layer; a second shield layer disposed over the first sensor element; and a second sensor element disposed between the first sensor element and the second shield layer, the second sensor element having a second free layer, wherein the second free layer is disposed a second distance from the second shield layer and wherein the second distance is substantially equal to the first distance.

BRIEF DESCRIPTION OF THE DRAWINGS

So that the manner in which the above recited features of the present invention can be understood in detail, a more particular description of the invention, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

FIG. **1** illustrates an exemplary magnetic disk drive, according to an embodiment of the invention.

FIG. **2**A is a side view of a read/write head and magnetic disk of the disk drive of FIG. **1**, according to one embodiment of the invention.

FIG. **2**B is a schematic cross-sectional view of portions of a read head of FIG. **2**A according to one embodiment of the invention.

FIG. **2**C is a schematic cross-sectional view of a current perpendicular to plane CPP read head according to one embodiment.

FIG. **2**D is a schematic cross-sectional view of a CPP read head according to another embodiment.

FIG. **2**E is a schematic cross-sectional view of a current in plane (CIP) read head according to one embodiment.

FIG. **2**F is a schematic cross-sectional view of a CPP read head according to another embodiment.

FIG. **3**A is a schematic cross-sectional illustration of a bottom TMR according to one embodiment.

FIG. **3**B is a schematic cross-sectional illustration of a top TMR according to one embodiment.

FIG. **3**C is a schematic cross-sectional illustration of a bottom CPP GMR according to one embodiment.

FIG. **3**D is a schematic cross-sectional illustration of a top CPP GMR according to one embodiment.

FIG. **4** is a graph showing a comparison of two reader element versus one reader element read heads.

To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements disclosed in one embodiment may be beneficially utilized on other embodiments without specific recitation.

DETAILED DESCRIPTION

In the following, reference is made to embodiments of the invention. However, it should be understood that the invention is not limited to specific described embodiments. Instead, any combination of the following features and elements, whether related to different embodiments or not, is contemplated to implement and practice the invention. Furthermore, although embodiments of the invention may achieve advantages over other possible solutions and/or over the prior art, whether or not a particular advantage is achieved by a given embodiment is not limiting of the invention. Thus, the following aspects, features, embodiments and advantages are merely illustrative and are not considered elements or limitations of the appended claims except where explicitly recited in a claim(s). Likewise, reference to "the invention" shall not be construed as a generalization of any inventive subject matter disclosed herein and shall not be considered to be an element or limitation of the appended claims except where explicitly recited in a claim(s).

The present invention generally relates to a read head in a magnetic recording head. The read head utilizes two reader elements that are stacked in the down track direction within the same read gap to improve resolution and SNR by combining the signals from the two reader elements. The output waveform from each read element is asymmetric in the down track direction; however, by use of equalizer settings and waveform combining, the combined waveform has a similar or better resolution and higher SNR compared to a single read element in a smaller read gap. The read heads have a resolution that is defined by the total distance between the free layer and the nearest shields. The read heads readers discussed herein are in contrast to the resolution for a single read head which is defined as the distance between the top and bottom shields.

FIG. **1** illustrates a top view of an exemplary hard disk drive (HDD) **100**, according to an embodiment of the invention. As illustrated, HDD **100** may include one or more magnetic disks **110**, actuator **120**, actuator arms **130** associated with each of the magnetic disks **110**, and spindle motor **140** affixed in a chassis **150**. The one or more magnetic disks **110** may be arranged vertically as illustrated in FIG. **1**. Moreover, the one or more magnetic disks **110** may be coupled with the spindle motor **140**.

Magnetic disks **110** may include circular tracks of data on both the top and bottom surfaces of the disk. A magnetic head **180** mounted on a slider may be positioned on a track. As each disk spins, data may be written on and/or read from the data track. Magnetic head **180** may be coupled to an actuator arm **130** as illustrated in FIG. **1**. Actuator arm **130** may be configured to swivel around actuator axis **131** to place magnetic head **180** on a particular data track.

FIG. **2**A is a fragmented, cross-sectional side view through the center of a read/write head **200** facing magnetic disk **202**. The read/write head **200** and magnetic disk **202** may correspond to the magnetic head **180** and magnetic disk **110**, respectively in FIG. **1**. In some embodiments, the magnetic disk **202** may be a "dual-layer" medium that includes a perpendicular magnetic data recording layer (RL) **204** on a "soft" or relatively low coercivity magnetically permeable underlayer (PL) **206**. The read/write head **200** includes an ABS, a magnetic write head and a magnetic read head, and is mounted such that its ABS is facing the magnetic disk **202**. In FIG. **2**A, the disk **202** moves past the head **200** in the direction indicated by the arrow **232**. The RL **204** is illustrated with perpendicularly recorded or magnetized regions, with adjacent regions having magnetization directions, as represented by the arrows located in the RL **204**. The magnetic fields of the adjacent magnetized regions are detectable by the sensing element **230** as the recorded bits. The write head includes a magnetic circuit made up of a main pole **212** and a thin film coil **218** shown in the section embedded in non-magnetic material **219**.

FIG. **2**B is a schematic cross-sectional view of portions of the CPP TMR read head according to one embodiment. The read head has two CPP TMR readers. The thickness of each layer, and the width of each layer, are for example only, and each layer may be thicker/thinner and/or wider/narrower. The read head includes a first shield layer S**1** and a second shield layer S**2** having the sensor structure **230** disposed therebetween. The first and second shield layers S**1**, S**2** may comprise a ferromagnetic material. Suitable ferromagnetic materials that may be utilized include Ni, Fe, Co, NiFe, NiFeCo, NiCo, CoFe and combinations thereof.

The sensor structure **230** comprises a top TMR **270** adjacent the first shield layer S**1** and a bottom TMR **272** adjacent the second shield layer S**2**. Between the top TMR **270** and the bottom TMR **272** is a center lead **274**. The center lead **274** may comprise a conductive material such as copper, tantalum, tungsten or chrome. In one embodiment, the center lead **274** may comprise a magnetic material. The presence of the ferromagnetic shield/material reduces the asymmetric waveform; however, the combined waveform has a better resolution and lower noise compared to each individual waveform.

FIG. **2**C is a schematic cross-sectional view of a CPP read according to one embodiment. The read head includes the first and second shield layers S**1**, S**2** along with the center lead **274** disposed between the top TMR **270** and the bottom TMR **272**. Bordering the sensor structure **230** is an insulating layer **240** that is disposed on the first shield layer S**1** as well as the sidewalls of the sensor structure **230**. The insulating layer **240** may comprise an insulating material such as aluminum oxide or silicon nitride. The insulating layer **240** may be deposited by well known deposition methods such as atomic layer deposition (ALD), chemical vapor deposition (CVD), and ion beam sputtering (IBD). On the insulating layer **240**, a magnetic bias layer **242** is then deposited. The bias layer **242** may comprise a single material or laminated magnetic materials such as CoPt, FePt, high moment CoFe or NiFe. Once the bias layer **242** is deposited, a bias capping structure **244** is formed over the bias layer **242**. In one embodiment, the bias capping structure **244** may comprise a multiple layered structure comprising one or combination of a tantalum layer, an iridium layer, a chromium layer, a titanium layer and a ruthenium layer.

The sensor structure **230** itself includes the center lead **274** disposed between the top TMR **270** and the bottom TMR **272**. The top TMR **270** includes an underlayer **276** disposed on the first shield layer S**1**. The underlayer **276** comprises hafnium, ruthenium, tantalum and combinations thereof. The underlayer **276** has a thickness of between about 15 Angstroms and about 75 Angstroms. In some embodiments, the underlayer **276** may comprise multiple layers.

On the underlayer **276**, a free layer **278** is deposited. The free layer **278** may comprise a single layer of magnetic material as shown or, in other embodiments, multiple layers. The free layer **278** may comprise Co, Fe, B, NiFe, CoFe, CoFeB and combinations thereof. The free layer **278** has a thickness of between about 15 Angstroms to about 75 Angstroms. The remainder **280** of the top TMR **270** is disposed on the free layer **278**.

The bottom TMR **272** includes a capping layer **286**, a free layer **284** and the remainder **282** of the bottom TMR **272**. The remainder **282** of the bottom TMR **272** is disposed on the center lead **274**. The free layer **284** is disposed on the remainder **282** and the capping layer **286** is disposed on the free layer **284** and below the second shield S**2**. The capping layer **286** comprises hafnium, ruthenium, tantalum or combinations thereof. The capping layer **286** has a thickness of between about 15 Angstroms and about 75 Angstroms. In some embodiments, the capping layer **286** may comprise multiple layers. The free layer **284** may comprise a single layer of magnetic material or, in other embodiments multiple layers. The free layer **284** may comprise Co, Fe, B, NiFe, CoFe, CoFeB or combinations thereof. The free layer **284** has a thickness of between about 15 Angstroms to about 75 Angstroms.

FIG. 2D is a schematic cross-sectional view of a CPP read head **288** according to another embodiment. As shown in FIG. **2**D, the read head **288** is similar to the read head from FIG. **2**C, however, the bias layer **242** and capping layer **244** are not present. Rather, the head **288** has the second shield S2 disposed over the insulating layer **240** to create a soft magnetic bias where a side shield is present. In the embodiment shown in FIG. **2**D, the second shield S2 is used as the side shield, but it is to be understood that a separate shield may be used instead of second shield S2. As shown in FIG. **2**D, two readers are contemplated to be present in a soft bias CPP read head.

FIG. **2**E is a schematic cross-sectional view of a current-in-plane (CIP) read head **290** according to one embodiment. The read head has insulating layers **291**, **292** between the shields S1, S2. Additionally, a center insulating layer **293** is present to isolate the sensors from each other. The sensors include the free magnetic layers **284**, **278** together with the remainder sensor material **290**A, **290**B. A conductive layer **294**, such as chromium, is used to separate the magnetic bias material (either soft or hard), from the sensors. As shown in FIG. **2**E, two readers are contemplated to be present in a CIP read head.

FIG. **2**F is a schematic cross-sectional view of a CPP read head **295** according to another embodiment. The read head **295** is utilizes a pair of scissor type sensors. The read head includes the two shields S1, S2 and the center lead **274**. On either side of the center lead **274** are the two readers. The readers comprise underlayers **295***a*, **295***f*, bottom free layers **295***b*, **295***g*, spacer layers **295***c*, **295***h*, top free layers **295***d*, **295***i*, and capping layers **295***e*, **295***j*. As shown in FIG. **2**F, two readers are contemplated to be present in a CPP scissor type read head.

FIG. **3**A is a schematic cross-sectional illustration of a bottom TMR **272** according to one embodiment. The bottom TMR **272** is disposed on the center lead **274**. The first layer of the bottom TMR **272** is an antiferromagnetic seed layer **302** that is disposed on the center lead **274**. The seed layer **302** comprises Ru, NiMnO or Ta and has a thickness of about 20 Angstroms to about 30 Angstroms. The seed layer **302** may be deposited by a thin film deposition process such as DC magnetron sputtering. On the seed layer **302**, an antiferromagnetic layer **304** is formed. The antiferromagnetic layer **304** comprises PtMn, IrMn, PtPdMn, NiMn or combinations thereof and has a thickness of about 60 angstroms. Similar to the seed layer **302**, the antiferromagnetic layer **304** is deposited by a thin film deposition process such as DC magnetron sputtering.

A pinned magnetic layer **306** is deposited on the antiferromagnetic layer **304**. The pinned magnetic layer **306** may comprise one of several types of pinned layers, such as a simple pinned, antiparallel pinned, self pinned or antiferromagnetic pinned sensor. For purposes of simplicity, the sensor will be described herein as a self pinned sensor having a pinned layer **306**, a reference layer **310**, and a non magnetic layer **308**, such as Ru sandwiched therebetween. The pinned and reference layers **306**, **310** can be constructed of several magnetic materials such as, for example NiFe, CoFe, CoFeB, or diluted magnetic alloys. The pinned magnetic layer **306** may have a thickness of between about 20 Angstroms and about 30 Angstroms and be deposited by a thin film deposition process such as DC magnetron sputtering. Similarly, the reference layer **310** may have a thickness of between about 20 Angstroms and about 40 Angstroms and be deposited by a thin film deposition process such as DC magnetron sputtering. The non magnetic layer **308** may be referred to as an antiparallel coupling layer and have a thickness of between about 5 Angstroms and about 10 Angstroms. The non magnetic layer **308** may comprise ruthenium and may be deposited by a thin film deposition process such as DC magnetron sputtering. An oxide barrier layer **312** is deposited on the reference layer **310**. The oxide barrier layer **312** comprises an insulating material such as MgO, HfO_2, TiO_2 or Al_2O_3. The oxide barrier layer **312** is the insulator between the magnetic reference layer **310** and the magnetic free layer **284** and thus, functions as the tunnel barrier between the two magnetic layers.

FIG. **3**B is a schematic cross-sectional illustration of a top TMR **270** according to one embodiment. The top TMR **270** comprises seed layer **276** and free layer **278**. Additionally, an oxide barrier **352** comprising MgO, HfO_2, TiO_2 or Al_2O_3 is present on the free layer **278**. The oxide barrier layer **352** is the insulator between the magnetic reference layer **354** and the magnetic free layer **278** and thus, functions as the tunnel barrier between the two magnetic layers. A magnetic reference layer **354**, nonmagnetic layer **356** and pinned magnetic layer **358** are disposed on the oxide barrier **352**. The pinned and reference layers **358**, **354** can be constructed of several magnetic materials such as, for example NiFe, CoFe, CoFeB, or diluted magnetic alloys. The nonmagnetic layer **356** comprises ruthenium. The pinned magnetic layer **358** may have a thickness of between about 20 Angstroms and about 30 Angstroms and be deposited by a thin film deposition process such as DC magnetron sputtering. Similarly, the reference layer **354** may have a thickness of between about 20 Angstroms and about 40 Angstroms and be deposited by a thin film deposition process such as DC magnetron sputtering. The non magnetic layer **356** may be referred to as an antiparallel coupling layer and have a thickness of between about 5 Angstroms and about 10 Angstroms. The non magnetic layer **356** may comprise ruthenium and may be deposited by a thin film deposition process such as DC magnetron sputtering. An antiferromagnetic layer **360** is disposed on the pinned layer **358** and below the capping layer **362**. The antiferromagnetic layer **362** comprises PtMn, IrMn, PtPdMn, NiMn or combinations thereof and has a thickness of about 60 angstroms. The antiferromagnetic layer **360** is deposited by a thin film deposition process such as DC magnetron sputtering. The capping layer **362** hafnium, ruthenium, tantalum and combinations thereof. The capping layer **362** has a thickness of between about 15 Angstroms and about 75 Angstroms.

The two reader elements are stacked in the down track direction within the same read gap to improve resolution and SNR by combining the signals from the two reader elements **270**, **272**. The output waveform from each read element is asymmetric in the down track, however, by use of equalizer settings and waveform combining, the combined waveform has similar or better resolution and higher SNR compared to a single read element in a smaller read gap.

The reader stack is highly asymmetric with respect to the free layer that produces the signal. The top pinned stack **270** and the bottom pinned stack **272** result in the free layer **278** of the top pinned stack **270** being closer to the bottom shield S1 and the free layer **284** of the bottom pinned stack **272** being closer to the top shield S2. By combining the waveform of the two readers, the resolution of the reader is given by the total of the closest distance between the free layers **278**, **284** and the shields Si, S2. By using a top pinned stack **270** close to the bottom shield Si and using a bottom pinned stack **272** close to the top shield S2, the closest separation between free layers and the shields, and therefore, very high resolution is achieved. In fact, up to 3 dB of SNR gain is possible. In one embodiment, the distance between the free layer **284** of the bottom pinned stack **272** and the top shield S**2** is equal to the distance between the free layer **278** of the top pinned stack **270** and the bottom shield S**1**.

A larger shield to shield spacing may be necessary to accommodate the two read elements **270**, **272** within the same gap (i.e., area between shields S**1**, S**2**) compared to having only one read element in the gap. However, the two read elements **270**, **272** are disposed in such a way whereby each of the free-layers **278**, **284** are much closer to a shield S**1**, S**2**, even though the total shield to shield spacing may be larger to accommodate the two readers. Consequently, a better resolution and SNR gain occurs.

FIG. **3**C is a schematic cross-sectional illustration of a bottom CPP GMR **370** according to one embodiment. FIG. **3**D is a schematic cross-sectional illustration of a top CPP GMR **380** according to one embodiment. The GMRs are similar to the TMRs described above with regards to FIGS. **3**A and **3**B; however, rather than oxide barriers **312**, **352**, a conductive layer **372**, **382** is present. In one embodiment, the conductive layer **372**, **382** may comprise copper.

In order to set the pinned magnetic layers in the sensors, the sensors are annealed after deposition of the antiferromagnetic layers. The annealing may occur at temperatures below about 280 degrees Celsius. Because the top and bottom sensors are formed separately, the magnetization is set separately. As such, the top sensor can degrade when the bottom sensor is set. In order to avoid degrading the top sensor when the bottom sensor is set, different antiferromagnetic material may be used for each sensor.

FIG. **4** is a graph showing a comparison of a two reader elements read head versus a one reader element read head. An SNR gain of greater than 1 dB is present by using two read elements between a larger shield to shield spacing compared to a single read element in a smaller shield to shield spacing. The single read element is placed at the center of the shield to shield spacing resulting in a symmetric waveform shown by the solid line. When two read elements are used (shown by the dashed line), and the use of equalized waveform and waveform combining, the combined waveform results in a resolution that is identical to the case of the single reader. Because of the waveform combining, the noise is reduced. Because the two read elements in this read configuration are placed such that the separation between the free magnetic layer of each of the read elements to the nearest shield is the same as the separation between the single element and the shields. Specifically, by using two read head sensors between the two shields, and reducing the total distance between the free magnetic layer and the nearest shield, the read head has an improved SNR and resolution in the down-track direction.

While the foregoing is directed to embodiments of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

What is claimed is:

1. A magnetic read head, comprising:
- a first shield layer;
- a second shield layer, wherein the second shield layer comprises a ferromagnetic material;
- a first sensor element disposed between the first shield layer and the second shield layer;
- a second sensor element, separate and distinct from the first sensor element, disposed between the first shield layer and the second shield layer;
- an insulating layer disposed on the first shield layer and on sidewalls of the first and second sensor elements; and
- a magnetic bias layer disposed on and in contact with the insulating layer, wherein the magnetic bias layer is in contact with the ferromagnetic material of the second shield layer.

2. The magnetic read head of claim **1**, wherein the first sensor element comprises:
- a first free magnetic layer;
- a first oxide barrier layer disposed on the first free magnetic layer;
- a first magnetic reference layer disposed on the first oxide barrier layer;
- a first nonmagnetic layer disposed on the first magnetic reference layer;
- a first pinned magnetic layer disposed on the first nonmagnetic layer; and
- a first antiferromagnetic layer disposed on the first pinned magnetic layer.

3. The magnetic read head of claim **2**, wherein the first oxide barrier layer comprises MgO, HfO_2, TiO_2 or Al_2O_3.

4. The magnetic read head of claim **3**, wherein the first magnetic reference layer comprises NiFe, CoFe, or CoFeB.

5. The magnetic read head of claim **4**, wherein the first nonmagnetic layer comprises ruthenium.

6. The magnetic read head of claim **5**, wherein the first free magnetic layer comprises NiFe, CoFe, or CoFeB.

7. The magnetic read head of claim **6**, wherein the first antiferromagnetic layer comprises PtMn, IrMn, PtPdMn, NiMn or combinations thereof.

8. The magnetic read head of claim **7**, wherein the second sensor element comprises:
- a second antiferromagnetic layer;
- a second pinned magnetic layer disposed on the second antiferromagnetic layer;
- a second nonmagnetic layer disposed on the second pinned magnetic layer;
- a second magnetic reference layer disposed on the second nonmagnetic layer;
- a second oxide barrier layer disposed on the second magnetic reference layer; and
- a second free magnetic layer disposed on the second oxide barrier layer.

9. The magnetic read head of claim **8**, wherein the second oxide barrier layer comprises MgO, HfO_2, TiO_2 or Al_2O_3.

10. The magnetic read head of claim **9**, wherein the second magnetic reference layer comprises NiFe, CoFe, or CoFeB.

11. The magnetic read head of claim **10**, wherein the second nonmagnetic layer comprises ruthenium.

12. The magnetic read head of claim **11**, wherein the second free magnetic layer comprises NiFe, CoFe, or CoFeB.

13. The magnetic read head of claim **12**, wherein the second antiferromagnetic layer comprises PtMn, IrMn, PtPdMn, NiMn or combinations thereof.

14. The magnetic read head of claim **8**, wherein the first antiferromagnetic layer and the second antiferromagnetic layer comprise different materials.

15. A magnetic read head, comprising:
- a first shield layer;
- a first sensor element disposed on the first shield layer;
- a center lead disposed on the first sensor element;
- a second sensor element disposed on the center lead; and
- a second shield layer disposed on the second sensor element, wherein the first sensor element comprises:
  - a seed layer disposed on the first shield layer;
  - a first free magnetic layer disposed on the seed layer;
  - a first oxide barrier layer disposed on the first free magnetic layer, wherein the first oxide barrier layer comprises MgO, HfO_2, TiO_2 or Al_2O_3;

a first magnetic reference layer disposed on the first oxide barrier layer, wherein the first magnetic reference layer comprises NiFe, CoFe, or CoFeB;

a first nonmagnetic layer disposed on the first magnetic reference layer, wherein the first nonmagnetic layer comprises ruthenium;

a first pinned magnetic layer disposed on the first nonmagnetic layer, wherein the first free magnetic layer comprises NiFe, CoFe, or CoFeB; and

a first antiferromagnetic layer disposed on the first pinned magnetic layer, wherein the first antiferromagnetic layer comprises PtMn, IrMn, PtPdMn, NiMn or combinations thereof.

16. The magnetic read head of claim **15**, wherein the second sensor element comprises:

a second antiferromagnetic layer, wherein the second antiferromagnetic layer comprises PtMn, IrMn, PtPdMn, NiMn or combinations thereof;

a second pinned magnetic layer disposed on the second antiferromagnetic layer, wherein the second pinned magnetic layer comprises NiFe, CoFe, or CoFeB;

a second nonmagnetic layer disposed on the second pinned magnetic layer, wherein the second nonmagnetic layer comprises ruthenium;

a second magnetic reference layer disposed on the second nonmagnetic layer, wherein the second magnetic reference layer comprises NiFe, CoFe, or CoFeB; and

a second oxide barrier layer disposed on the second magnetic reference layer, wherein the second oxide barrier layer comprises MgO, HfO_2, TiO_2 or Al_2O_3; and

a second free magnetic layer disposed on the second oxide barrier layer.

17. The magnetic read head of claim **16**, wherein the center lead comprises a nonmagnetic conductive material comprising copper, chromium, tantalum or tungsten.

18. The magnetic read head of claim **15**, wherein the center lead is magnetic.

19. A magnetic read head, comprising:

a first shield layer;

a first sensor element disposed on the first shield layer, wherein the first sensor element comprises:

an underlaver disposed on and in contact with the first shield layer;

a first free magnetic layer disposed on and in contact with the underlayer, wherein the first free magnetic layer is disposed a first distance from the first shield layer;

a first oxide barrier layer disposed on and in contact with the first free magnetic layer wherein the first oxide barrier layer comprises MgO, HfO_2, TiO_2 or Al_2O_3;

a first magnetic reference layer disposed on and in contact with the first oxide layer, wherein the first magnetic reference layer comprises NiFe, CoFe, or CoFeB;

a first nonmagnetic layer disposed on and in contact with the first magnetic reference layer, wherein the first nonmagnetic layer comprises ruthenium;

a first pinned magnetic layer disposed on and in contact with the first nonmagnetic layer; and

a first antiferromagnetic layer disposed on and in contact with the first pinned magnetic layer, wherein the first antiferromagnetic layer comprises PtMn, IrMn, PtPdMn, NiMn or combinations thereof;

a second shield layer disposed over the first sensor element; and

a second sensor element disposed between the first sensor element and the second shield layer, the second sensor element having a second free layer, wherein the second free layer is disposed a second distance from the second shield layer and wherein the second distance is substantially equal to the first distance, and wherein the second sensor element comprises:

a second antiferromagnetic layer disposed on a seed layer, wherein the second antiferromagnetic layer comprises PtMn, IrMn, PtPdMn, NiMn or combinations thereof;

a second pinned magnetic layer disposed on the second antiferromagnetic layer;

a second nonmagnetic layer disposed on the second pinned magnetic layer, wherein the second nonmagnetic layer comprises ruthenium;

a second magnetic reference layer disposed on the second nonmagnetic layer, wherein the second magnetic reference layer comprises NiFe, CoFe, or CoFeB;

a second oxide barrier layer disposed on the second magnetic reference layer, wherein the second oxide barrier layer comprises MgO, HfO_2, TiO_2 or Al_2O_3; and

the second free magnetic layer disposed on the second oxide barrier layer.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,230,578 B2
APPLICATION NO. : 14/138804
DATED : January 5, 2016
INVENTOR(S) : Batra et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Claims:

Column 9, Claim 19, Line 41, please delete “underlaver” and insert --underlayer-- therefor.

Signed and Sealed this
Twenty-sixth Day of April, 2016

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office